NUCLEAR POWER AND ITS ROLE IN LIMITING CO_2 EMISSIONS

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ABSTRAK

NUCLEAR POWER AND ITS ROLE IN LIMITING CO2 EMISSIONS. *The objective of this study is to analyze the proper role of nuclear power in the long term energy planning by comparing different type of scenarios in terms of CO2 emission reduction, based on the Business-as-Usual (BAU) scenario. For this purpose, a MESSAGE (Model of Energy Supply Systems and their General Environmental impacts) was used to develop energy planning as well as CO2 emission projection. A sensitivity analysis for CO2 reduction rates of 2%, 3%, 4% and 5% have been done. From this sensitivity analysis, it can be concluded that nuclear will be a part of optimum solution under CO2 limitation of at least 3% from BAU condition. The more the environmental standards are tightened and enforced the more and the earlier nuclear power becomes part of the optimum generation mix.*
Keywords: *nuclear energy, CO_2 emission*

ABSTRACT

ENERGI NUKLIR DAN PERANNYA DALAM PEMBATASAN EMISI CO2. *Tujuan dari studi ini adalah untuk melakukan analisis peran dari energi nuklir dalam perencanaan jangka panjang dengan cara membandingkan beberapa skenario yang berbeda dalam hal pengurangan emisi CO2, didasarkan pada skenario Business-as-Usual (BAU.) Untuk tujuan ini, model MESSAGE (Model of Energy Supply Systems and their General Environmental impacts) digunakan guna menyusun perencanaan energi termasuk proyeksi emisi CO2. Analisis sensitivitas untuk tingkat pengurangan CO2 dibuat dengan besaran 2%, 3%, 4% and 5%. Dari analisis sensitivitas dapat disimpulkan bahwa nuklir akan menjadi bagian dari solusi optimal pada kondisi pembatasan CO2 minimal 3% dari skenario BAU. Semakin ketat dan pemaksaan standar lingkiungan akan semakin awal energi nuklir menjadi bagian dari bauran pembangkitan yang optimal.*
Kata kunci: *energi nuklir, emisi CO_2*

I. INTRODUCTION

Thermal power plants generate electricity by burning fossil fuels such as petroleum, coal and natural gas. This combustion process is the source of CO_2 emissions, which causes global warming. Nuclear power generation, in contrast, harnesses the heat energy produced by nuclear fission. Because there is no combustion involved in the process, nuclear power generation does not emit CO_2 in principle. Furthermore, indirect CO_2 emissions from processes such as mining/transportation of fuels and development/operation of power stations are miniscule. While a natural gas-fired combined cycle plant, which is the most efficient power generation option, emits approximately 519g of CO_2 to generate 1 kWh of electricity, a nuclear power plant emits only about 22-25g of CO_2 and can generate the same amount of electricity[1]. In short, nuclear power generation is an eco-friendly way of generating electricity from the viewpoint of the prevention of global warming.

At the present time, fossil energy have been selected as the major electricity sources and provide more than 84% of total electricity generation in Indonesia[2]. National energy policy addressing environmental friendliness has made it difficult to decide which energy resource is the best for the long term energy planning[3]. Although climate change regime will diminish the fossil power plants in generation amount, the public still keeps nuclear at a distance and insists to replace nuclear by renewable. The renewable does not any guarantee of stable supply although its economics is being speedily improved. Therefore, it is necessary to analyze the long-term power expansion planning in various points of view such as the benefit of carbon reduction.

The objective and approach of this study are to analyze the proper role of nuclear power in the long term energy planning by comparing the different types of scenarios in terms of CO_2 emission reduction, based on Business as Usual (BAU) scenario. For this purpose, a MESSAGE model was used to develop energy planning as well as CO_2 emission projection[4]. The study was focused on the electricity expansion planning in Sumatera-Jawa-Bali system.

2. METHODOLOGY

The energy demand projections were computed using MAED (**M**odel for **A**ssessment of **E**nergy **D**emand) with the key drivers of energy demand, namely demography, socio-economy and technology. The application of MAED requires detailed information on demography, economy, energy intensities and energy efficiencies. This information is first assembled for a base year which is used as the reference year for perceiving the evolution of the energy system in the future. Selection of the base year is made on the basis of availability of data, assessment that the data is representative of the economic and energy situation of the country [5]. MAED allows the breakdown of the country's final energy consumption into various sectors and within a sector into individual categories of end-uses in a consistent manner.

The total energy supply were computed using MESSAGE (**M**odel of **E**nergy **S**upply **S**ystems and their **G**eneral **E**nvironmental impacts) and utilizes the projected energy demand as an input to produce a supply strategy. MESSAGE is an energy supply model, representing energy conversion and utilization processes of the energy system (or its part) and its environmental impacts for an exogenously given demand of final energy. It is used for development of long-term strategies, the planning horizon being in the order of 50 years. The time scope is limited due to uncertainties associated with future technological development. The energy system dynamics are modeled by a multi-period approach. It is an optimization model which, from the set of existing and possible new technologies, selects the optimal in terms of selected criterion mix of technologies able to cover a country's demand for various energy forms during the whole study period.

MESSAGE takes into account demand variations of various final energy forms during the day, week and year, as well as different technological and policy constrains of energy supply. It is an energy and environmental impact model, enabling the user to carry out integrated analysis of the energy sector development and its environmental impacts. The application of the MESSAGE model results in a least-cost inter-temporal mix of primary energy, energy conversion and emission control technologies for each scenario. For the computation of Indonesia's Energy Supply the same scenario that was used in MAED are used.

3. DATA AND ASSUMPTIONS

3.1. Carbon Dioxide Emissions from Power Generation

Nuclear energy is among those energy sources producing very low levels of carbon dioxide emissions from their full life cycle. It is closely comparable with renewables such as wind, solar and hydro in this respect.

In recent years, mining companies have been publishing their energy use as part of broader environmental or social responsibility disclosure - part of product stewardship. Also some utilities generating power have undertaken Life Cycle Analysis (LCA) studies as part of their social accountability. Both kinds of results have been audited and published.

The principal focus of LCA for energy systems today is their contribution to global warming. There is an obvious linkage between energy inputs to any life cycle and carbon dioxide emissions, depending on what fuels those inputs. LCA includes mining, fuel preparation, plant construction, transport, decommissioning and managing wastes.

In the nuclear fuel cycle energy inputs are low, even with diminishing ore grades. It's very large low-carbon advantage over fossil fuels will remain even then. In fact uranium resources are abundant and the need to access extremely low grade ores is far off. The comparison of CO_2 emission is shown in Figure 1.

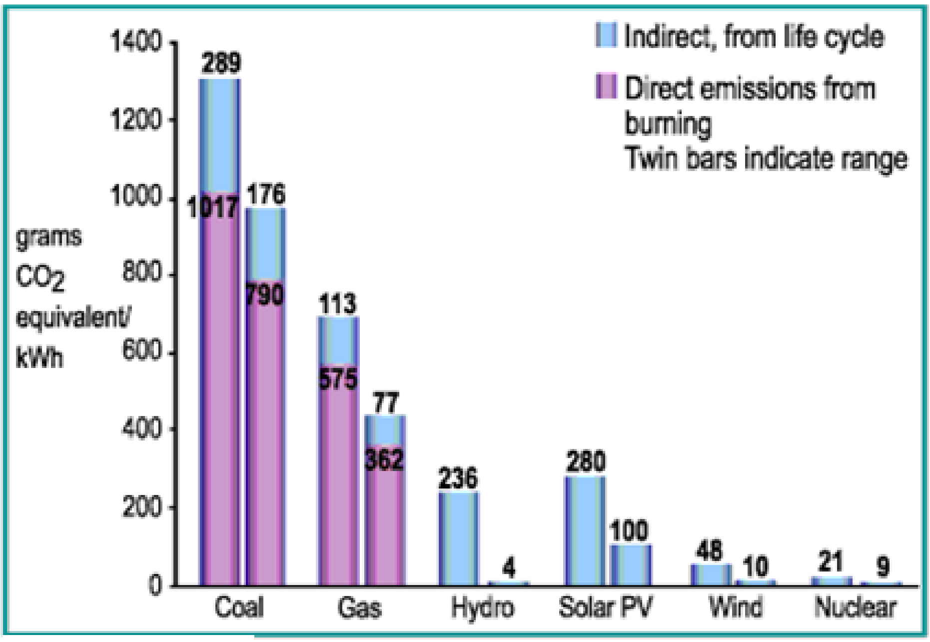

Figure 1. Comparison of CO_2 Emission of Power Plants[6]

3.2. Technology Options for Electricity Generation

The following technology options for capacity expansion or replacement of retired generating capacity were modeled. The power plants for the future development in Indonesia consist of: Geothermal, Coal 600 MW, Coal Supercritical 1000 MW, Coal with Carbon Capture Storage 1000 MW, IGCC (Integrated gasification combined cycle), Gas Turbine, Solar, Wind, Biomass, Nuclear and Hydro.

3.3. Scenarios Development

Two scenarios were developed for the quantitative analysis and comparison of the potential impacts of nuclear technology on Indonesia electricity and energy system was developed:

1. Business-as-Usual (BAU) scenario. In this scenario it is assumed that the condition continues to rely on current type of fuels without CO_2 limitation policy.
2. CO_2 limitation (CO_2 Low) scenario is included based on National Policy on CO_2 reduction that in year 2020 CO_2 from energy, transportation and industry sectors will be reduced by 5.1% from BAU.

This study uses a constant 10% real discount rate and no escalation in the fuel prices and the investment and O&M costs.

4. ANALYSIS RESULT

The quantitative results of BAU scenario are presented in some detail, as BAU is the basis against which all other scenarios are compared. The 2020-2025 period, during which the nuclear units are planned to be installed, is of special interest since the purpose of this study is to gain a better understanding of the potential impacts of the nuclear power installation in terms of operation, costs, and capacity expansion of the entire electricity and energy system. The presentation of the scenario results here focus particularly on this period.

4.1. BAU Scenario

A BAU scenario does not mean that there is no change, but the change here manifests itself through technology evolution and efficiency improvements without any deep-reaching structural change in Indonesia electricity and energy system. Despite the large availability of still-operational pre 2010 generating capacities, the model substitutes more fuel-efficient technology and, to the lesser extent, new coal technology.

Net electricity generating capacity of Indonesia multiplies more than nine times over the time horizon, from 37 GW on average during 2010 to 344 GW in 2050. Figure 3.9 shows the capacity evolution by major generation sources.

The share of oil based capacity in total net generating capacity decreases from 33 % to 5 % in year 2025 and becomes 0% in 2050. The reason is that oil price will increase and Indonesia oil resources will diminish after 2030. PLN (electricity utility company) have a plan to reduce and shift oil power plant to gas or renewable energy such as hydro pump storage for peak-load supply. The share of coal based capacity increases from 23 % to 45 % and becomes 62% in 2050. The share of gas based capacity decreases from 25% to 20% and becomes 19% in 2050. Hydro, and geothermal power plant capacities grow from 11% to 14% and 3% to 10% respectively but decrease after year 2025 by 11% and 6% at the end of time horizon, respectively. The additions to hydro and geothermal power capacity are assumed to become possible mainly outside Jawa.

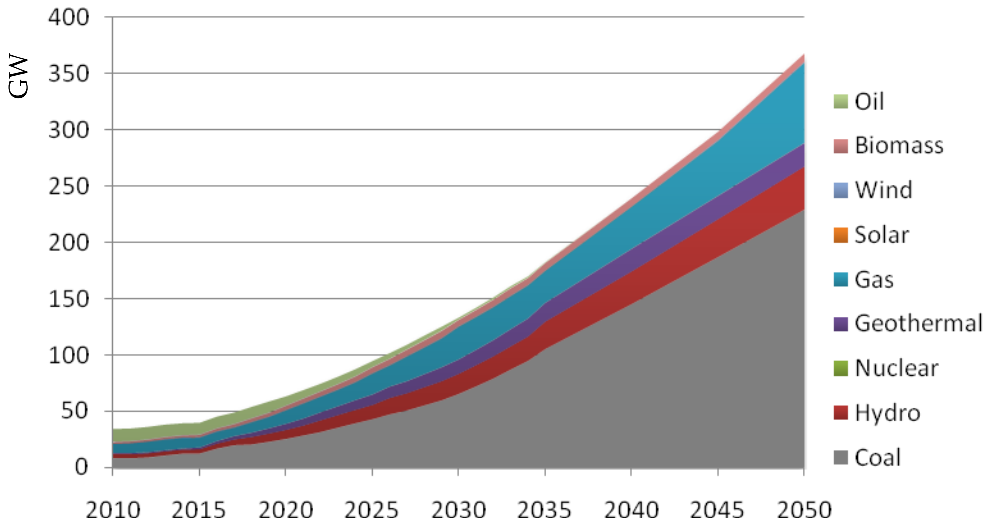

Figure 2. Net Electricity Generating Capacity by Types of Source, Indonesia (GW)

Nuclear energy is not present in the BAU scenario. Under the criterion of least cost and the assumptions on availability and, for the supply of Jawa-Sumatera, accessible resources, cost of fossil based and nuclear power plants, and the development of fuel prices, nuclear power does not become part of the optimum generation mix.

4.2. CO_2 Low Scenario

Installed capacity of Indonesia in CO2 Low scenario is a little higher than in BAU scenario. Generating capacity in CO2 Low scenario is increase from 34 GW on average during 2010 to 370 GW in 2050 or 6 GW difference from BAU scenario. The reason is because in CO2 Low scenario more renewable energy contributed, and the renewable energy has lower capacity factor than fossil power plant. So, to produce same amount of energy, need more capacity if using renewable technology. Figure 3 shows the capacity evolution by major generation sources.

In CO_2 Low scenario, coal based capacity still dominant with contribution on in electricity supply increases from 23 % to 47 % and becomes 57% in 2050. The share of gas based capacity decreases from 25% to 17% and steady until 2050. Hydro, and geothermal power plant capacities grow from 11% to 14% and 3% to 10% respectively but decrease after year 2025 by 11% and 6% respectively at the end of time horizon.

Nuclear energy is present in the CO_2 Low scenario and the share of nuclear increase from 0% in 2010 to 4% in 2025 and become 8% in 2050. Under CO_2 reduction scenario will reduce the fossil power plants in generation amount and replaced by new and renewable energy such as nuclear.

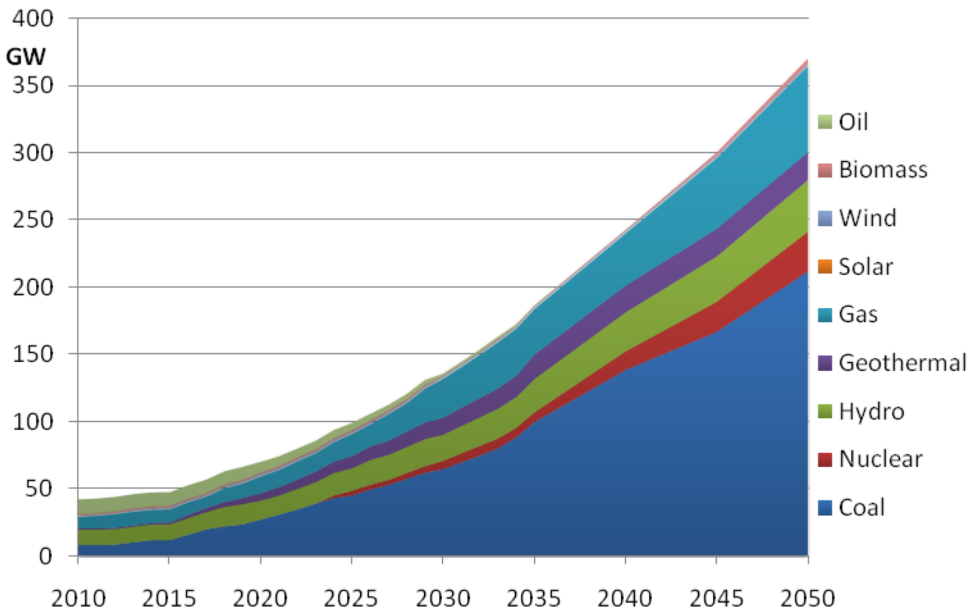

Figure 3. Net Electricity Generating Capacity by Types of Source, Indonesia (GW)

4.3. Electricity Generation

Under the CO_2 low, Indonesia's total electricity generation increases from some 194 TWh in 2010 to 2043 TWh in 2050 or with growth rate of 6.6% per year as shown in Figure 3.16. Meanwhile for Jawa-Bali-Sumatera system, electricity generation increases from 152 TWh in 2010 to some 2003 TWh in 2050.

The CO_2 Low Scenario highlights the expansion plan in Jawa-Bali-Sumatera are as follows:

- The share of electricity generation from coal changes significantly during the period, providing 30% in 2010 to 61% in 2050. The share of coal in 2050 decreases 9% from BAU scenario which is 70%.
- Nuclear gives contribution starting from 2024 and the share increases from 5% in 2025 to be 10% in 2050
- The share of gas decrease from 28% in 2010 to 19% in 2025 and changes a little during the 2025 – 2050 period to 16%.
- The share of hydro also decreases due to resources limitation from 10% in 2010 to 5% in 2050.
- Geothermal generates electricity and gives contribution of 6% in 2010 and stabilizes until the end of period study.

4.4. Result Comparison between Scenarios

Figure 4 shows the percentage share comparison resulted from the model between the two scenarios. The graph on the left is the installed capacity for coal, nuclear and other technologies (gas, hydro, wind, oil etc.) over the study period for BAU scenario while the graph on the right is CO_2 limitation scenario.

When compare the reference (BAU) and environment constraint scenarios, it is discovered that nuclear will come in the system starting from 2024 and increases from 3 GW to 30 GW in 2050. This fact reveals a substitutive relationship between coal and nuclear power in providing electricity.

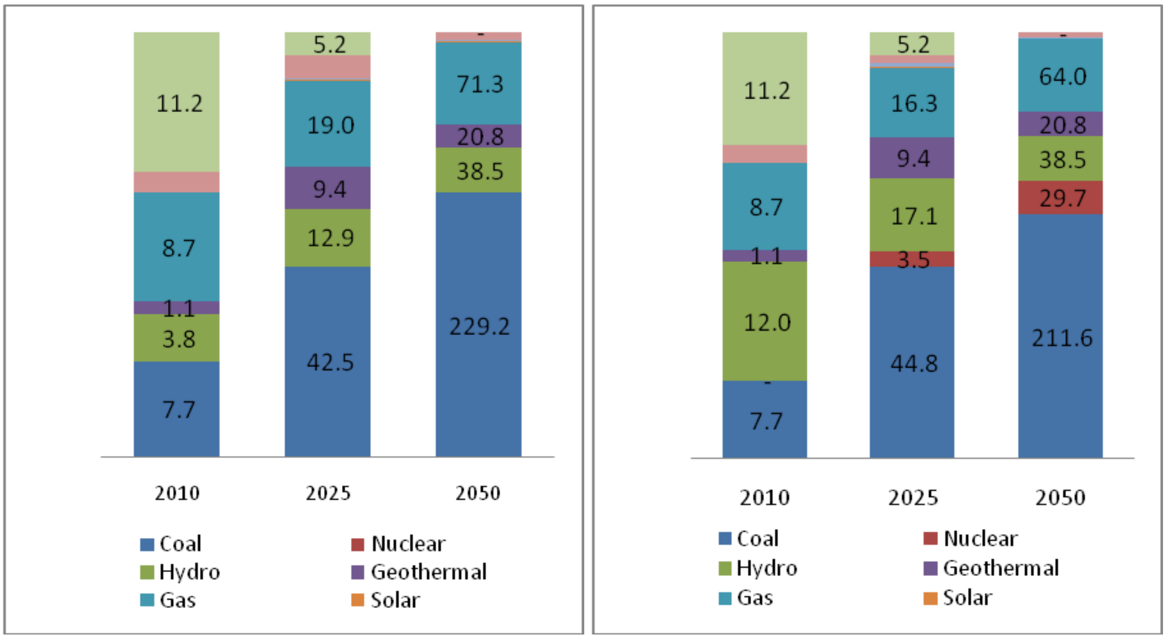

Figure 4. Installed Capacity (GW): BAU scenario (left), CO_2 limitation (right)

4.5. Fuel Consumption

Primary fuel requirement comparison for electricity generation is summarized in Figure 5. Total fuel requirements in BAU scenario increase from about 1,250 Peta Joule (PJ) in 2010 to 14,756 PJ in 2050 with an average growth rate of 6.3%.

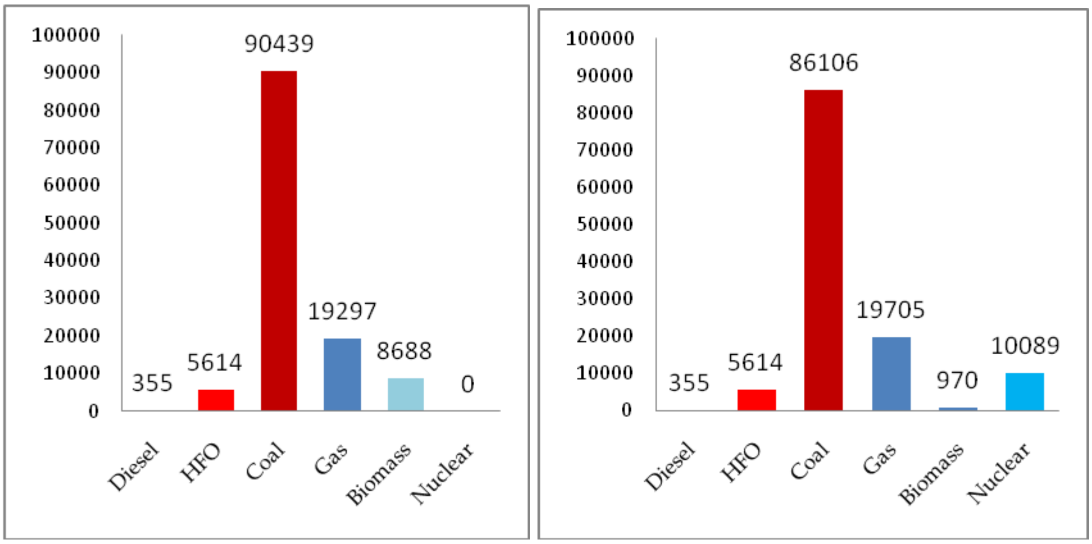

Figure 5. Fuel Consumption (PJ) Comparison between Scenarios, BAU (left) and CO_2 Low (right)

The CO_2 limitation scenario or CO_2 Low scenario will reduce fuel consumption especially fossil fuel that have high CO_2 emission factor such as biomass and coal. From the simulation results, it is shown that coal fuel consumption decreases from 90,438 PJ in BAU scenario to 86,105 PJ in CO_2 Low scenario or 5% reduction. Biomass has significant reduction from 8,688 PJ in BAU scenario to 970 PJ in CO_2 Low scenario or 88% reduction. This is because biomass has higher CO_2 emission factor than others.

4.6. Sensitivity Analysis

The scenario analysis presented in the previous section reflects an inherent set of assumptions regarding future values of critical input parameters. The following three key input parameters underlying the competitiveness of nuclear power in the context of the Indonesia electricity and energy system were:

- Investment cost of nuclear power
- Investment cost of coal power
- CO_2 limitation

4.6.1. NPP Investment Cost

Cost figures for nuclear power plants vary widely reflecting the importance of national conditions and the lack of recent construction experience in many countries. For the nuclear power plants in the International Energy Agency and Nuclear Energy Agency (IEA/NEA) and OECD study, the overnight construction costs vary between 1,600 and 5,900 USD/kWe with a median value of 4,100 USD/kWe. The study considers different Generation III technologies including the EPR, other advanced pressurized water reactor designs as well as advanced boiling water reactor designs[7].

Some variations are due to local differences. Building on a green field site is generally more expensive than building on a site with existing reactors. Building in a more seismically active area is more expensive. Labor and material costs vary, and their impact varies with the localization rate, i.e. the percentage of plant components that are locally manufactured or procured.

For Indonesia, which is preparing for the first-time construction of nuclear power plant, infrastructure and site preparation cost may be substantial. In the scenario analysis, an investment cost of 3500, 4000, 4500 (base case) and 5000 USD/kWe was carried out. Nuclear will be an integral part of the cost-optimal electricity supply mix at investment cost up to 3500 USD/kWe.

4.6.2. Investment Cost of Coal Power Plant

Compared with nuclear power, the upfront costs of installing coal power plant are not as critical (low investment cost, low investment risk). Yet coal capital costs are also a major component of generating cost, and lower specific investment cost may improve the competitiveness of coal-based electricity versus nuclear generation. Moreover, coal power capital costs are very much a function of pollutant abatement regulation, and coal plant manufacturers have been facing price hikes in their material and energy costs similar to nuclear power. The capital cost of 1650 $/kW for coal power plant applied in this study is, internationally, very low. In the scenario analysis, investment costs of 1800, 2000, and 2500 USD/kWe were used.

With an investment cost of 2500 USD/kWe for coal power plant, nuclear will become an integral part of the cost-optimal electricity supply mix.

4.6.3. CO_2 Limitation

Various effects have been discussed in this study of a weighted constraint on the use of fossil fuels causing pollution, as can be achieved through CO_2 reduction targets for the energy industry. Figure 6 visualizes the installed capacity of nuclear power plants (GW) for

CO_2 reduction rates between 2%, 3%, 4% and 5%. At CO_2 reduction rate of 3 %, nuclear will be a part of optimum solution starting from 2024 and it is set as a target of NPP operation.

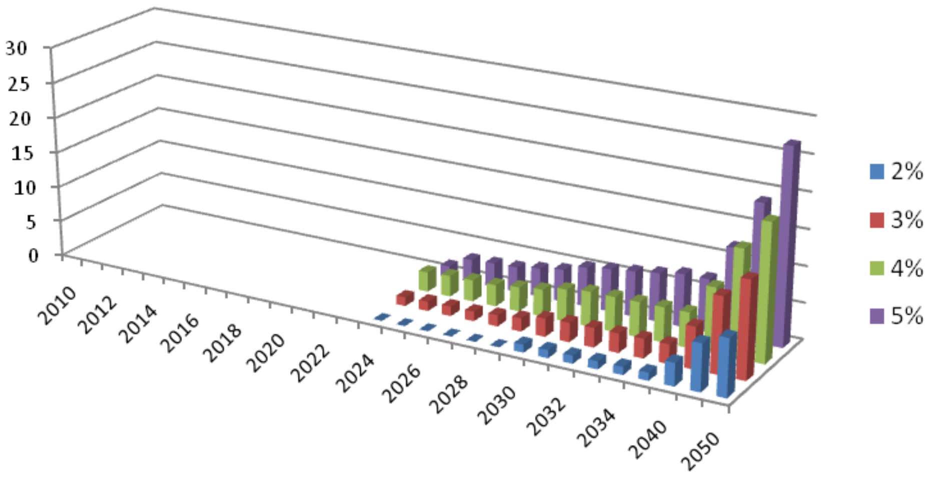

Figure 6. Nuclear Power Capacity (GW) for Various CO_2 Limitations

From this sensitivity analysis, can be concluded that nuclear will be a part of optimum solution under CO_2 limitation of at least 3% from BAU condition. The more the environmental standards are tightened and enforced the more and the earlier nuclear power becomes part of the optimum generation mix.

5. CONCLUSION

Indonesia's economy was heavily a fossil fuel intensive. Although Indonesia currently contributes relatively low of the global energy related CO_2 emission, this share is expected to increase in the future due to growing energy demand that is associated with rapid urbanization and industrialization, and lack of GHG mitigation measures and policies.

It can be concluded that based on the assumption and the scenarios analyzed in this study and in line with the Government of Indonesia policy on enviroment, especially in the reduction of CO_2 emission, the prospect of nuclear power as a competitive and non emission carbon energy will become a part of optimal solution in Indonesian electricity generating system and also nuclear energy will have important role in strengthening energy security and mitigating climate change nuclear power becomes part of the optimum generation mix.

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